Physics 343 Lecture # 3:
Lab # 1; Radiative Processes;
Temperature Scales

Scheduling

For analysis weeks, we will hold optional "on call" office hours at lab times in addition to regular office hours. This week:

Sections A, C, F, & G: Baker, Serin 309W

Sections B, D, E, & H: Rivera, ARC 220

plus "regular" office hours Thursday 5:00–6:00pm (Rivera) and Friday 3:20–4:40pm (Baker).

Next Monday:

+ lab report # 1 due

+ observations for lab # 2 will begin

Data for lab #1

You should receive your data by email later today. Telescope drive issues mean some of you will receive archival datasets.

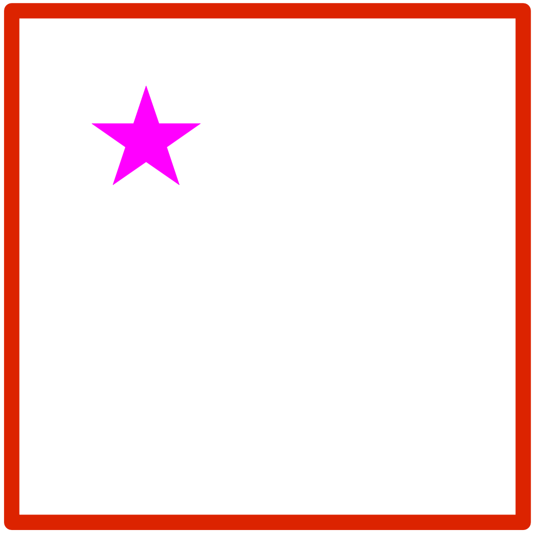
Clarifications about observing scripts...

- **commands are case-sensitive! "sun n" and "Offset 0 10" will not be recognized, and will be skipped**
- **raster scan corrections are written to data file but overwritten when a new "offset" command is issued**
- **in some cases, fewer positions observed to avoid having telescope run into (typically elevation) limits**
- **simulation mode writes out data faster than reality**

Pointing

Telescope's pointing solution is not perfect and can vary significantly with position on the sky.

Keep this in mind when you compare your datasets!



Do you need new data?

If you can do the analysis with the data you have, even if they don't look perfect, like your lab partners', etc., then NO. You may need to make (and explain) decisions about particular points that you ignore, but you will not be penalized for imperfect data.

If you cannot do the analysis with the data you have (the sun is not detected, the data are overwhelmed with noise, etc.) then YES– but you need to tell me by Friday to get a replacement dataset.

A reminder: loading data into Excel

Thans to Alex Merced (Rutgers '08):

(1) Copy the original raw data file into a safe backup version, since Excel actually works directly on any input file.
(2) Click File → Open (set filter to select all files). Proceed to the "Text Import" wizard, and read in delimited input (deselect tab, select space as delimiter; treat consecutive delimiters as a single one).
(3) As a fallback, you can use the "Text Data to Columns" button to access the "Text Import" wizard.

The SRT's receiver

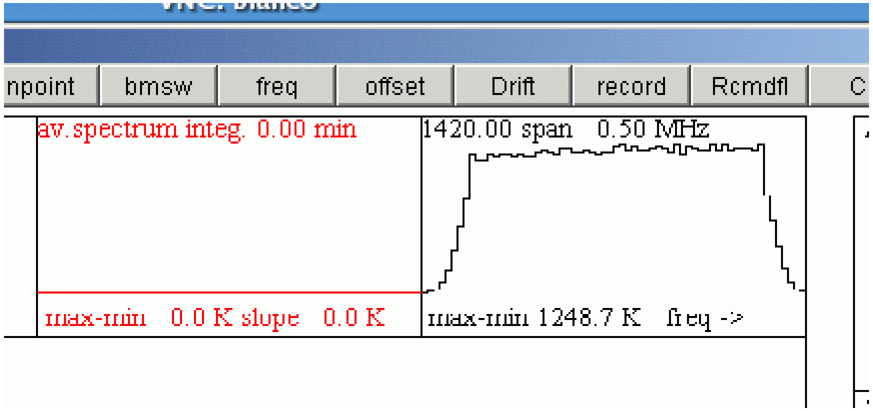
The telescope on the roof of Serin is equipped with the digital receiver rather than the analog receiver (digital systems use digital signals, i.e., 1s and 0s, while analog systems use signals that are continuous in time and amplitude).

Output is one long row per time dump, containing:
time stamp, azimuth, elevation, azimuth offset, elevation offset, frequency, channel spacing, spectral mode (typically 1), # of spectral bins (typically 64), and contents of those bins.

Two tips for analysis

(1) The SRT output is an array of antenna temperature (units K). The observed antenna temperature is due to a combination of the Sun and of internal noise from the instrument.

(2) Remember that the typical shape of the spectrum is due to the instrument response rather than the Sun itself... so think carefully about how you want to deal with the end channels.



Another reminder: content of lab reports

Do include:

- **(1) a brief description of the purpose of the observations**
- **(2) a brief description of the observations (e.g., how many data points per offset? was the script modified in any way?)**
- **(3) a description of your analysis (number-crunching)**
- **(4) a discussion of your results (plots and sketches help; consider your sources of uncertainty)**
- **(5) a summary of your most important conclusions**

Do not include:

- **(1) the full script**
- **(2) the raw data**

Write in active voice ("We did…"), and be faithful to the data!

Errors: random and systematic

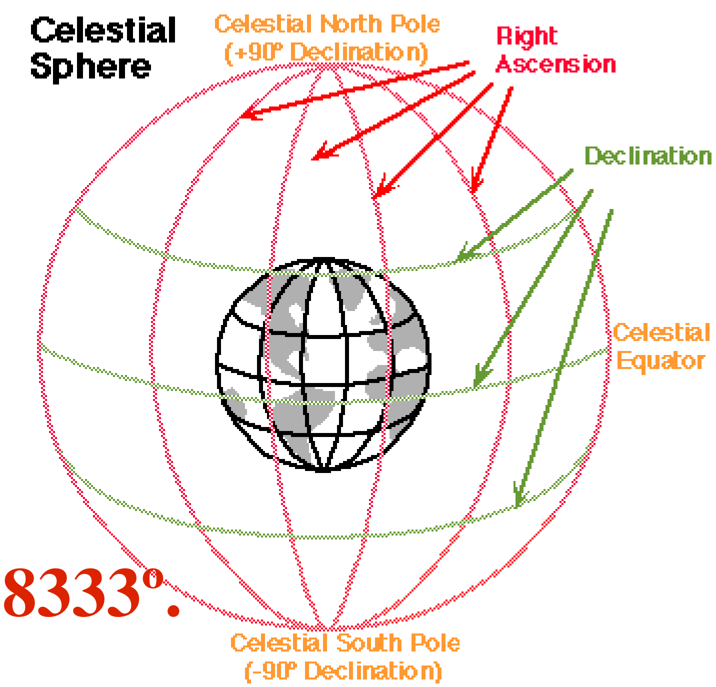
When we make a measurement, we do so imperfectly due to both random and systematic errors.

Random errors average away with more measurements. We often assume that these follow a Gaussian probability distribution (more on this later).

Systematic errors do not average away. Getting more data doesn't always help!

Celestial coordinates: units of R.A.

Right ascension ("R.A.", α) & declination ("Dec.", δ) = celestial latitude and longitude that describe a source's position.



Example # 1:

A source has R.A. 14:11:45.2.

What is this in units of degrees?

Answer:

$15 \times (14 + 11/60 + 45.2/3600) = 212.938333^{\circ}$.

(Note that R.A. 23:59:59 corresponds to 359.995833°.)

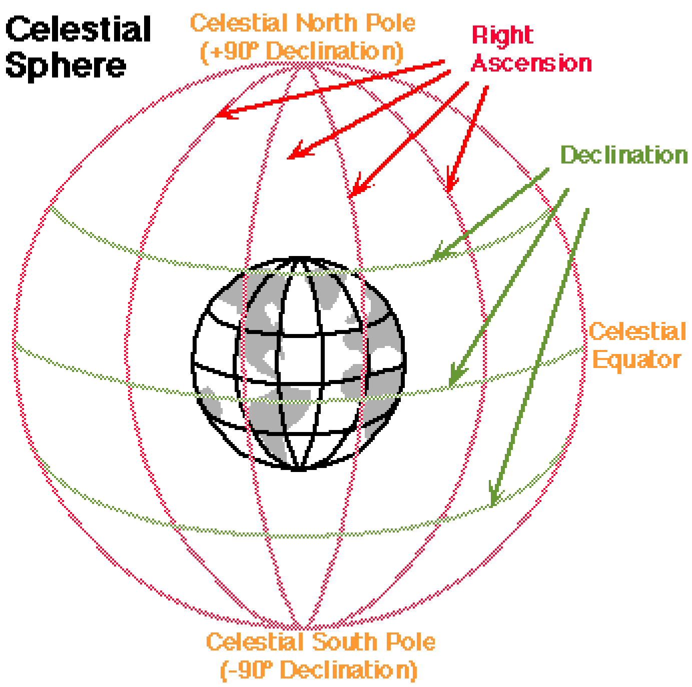
Celestial coordinates: source separations

Example # 2:

Source A lies at 02:33:24.5 +15:32:29.

Source B lies at 02:33:32.9 +15:24:06.

How far apart are they on the sky?



Answer:

$\Delta\delta$ **is easy:** $(24 \times 60 + 6) - (32 \times 60 + 29) = -503'' = -8.383'$

$\Delta\alpha$ **is harder:** $15 \times (32.9 - 24.5) \times \cos(15.4715) = 121'' = 2.024'$

For small angles, separation $\simeq [(\Delta\delta)^2 + (\Delta\alpha)^2]^{1/2} = 8.6'$

Celestial coordinates: directions

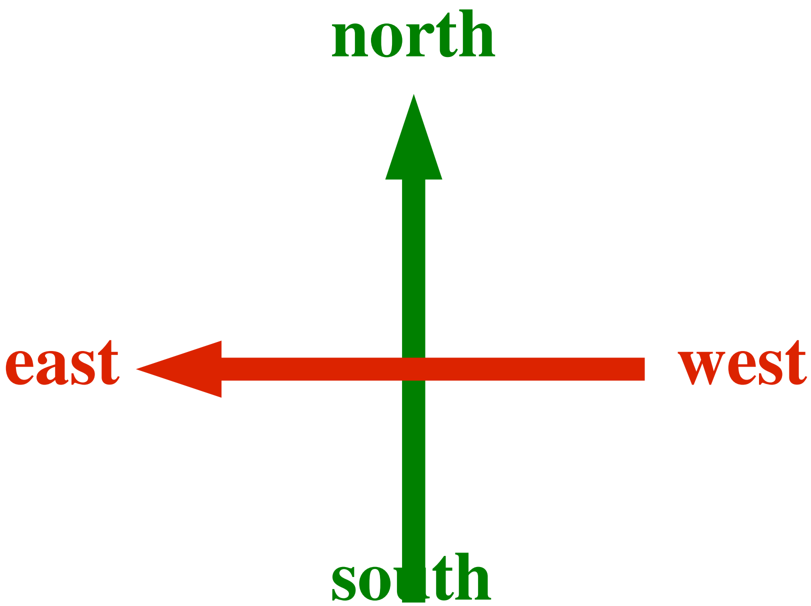
Consider again: source A lies at 02:33:24.5 +15:32:29,

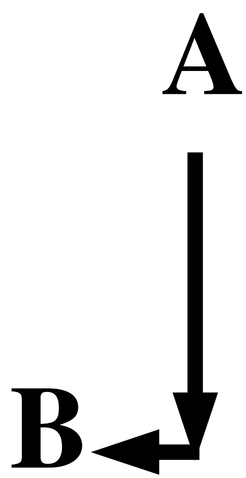
source B lies at 02:33:32.9 +15:24:06.

How do they *look* on the sky?

$\Delta\delta = -8.383'$

$\Delta\alpha = 2.024'$





Celestial coordinates: precession

When can a source's right ascension and declination change?

(1) It's a solar system object (Sun, moon, planet, asteroid, etc.).

(2) It's a nearby star with a high "proper motion" (e.g., α Cen).

(3) We wait long enough that the earth's rotation axis wobbles a little (i.e., it precesses).

To deal with (3), every right ascension and declination must be specified with an epoch ("B1950" and "J2000" are common).

Celestial timekeeping

Astronomers use two principal time conventions:

(1) UT = Universal Time

This is a solar time that corresponds (apart from daylight savings) to the local time in Greenwich, England.

At a given moment, UT is the same everywhere.

(2) LST = Local Sidereal Time

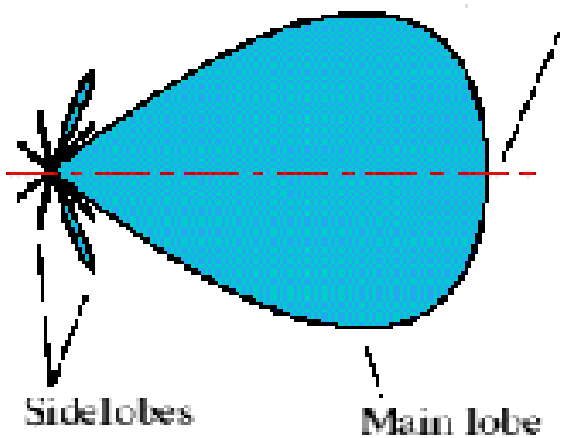
This is the R.A. that is directly overhead right now.

At a given moment, LST is different at different longitudes.

Lab # 1: measuring the telescope's beam

A radio telescope can only see a limited range in solid angle (relative to its own axis) at any given time.

The normalized beam pattern describes a telescope's response to a given sky direction (defined to be 1 on-axis).



The main lobe has a width proportional to λ/D for λ the wavelength and D the diameter of the telescope. We are measuring the width of the main lobe for the SRT by scanning across the sun.

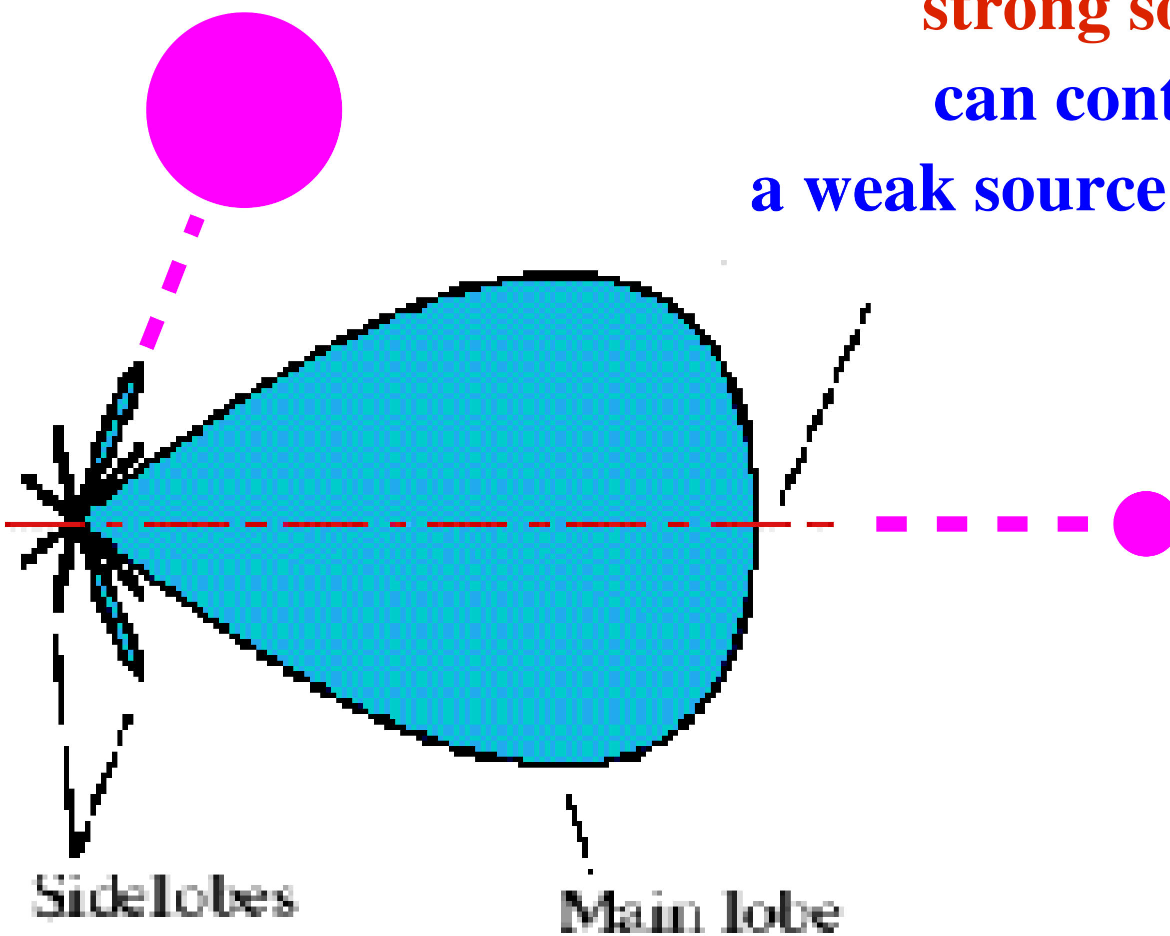
Why we care about the telescope's beam

Shape of the beam corresponds to the weighting in a particular direction of the total summed response:

strong source in a sidelobe

can contribute as much as

a weak source in the main beam!



Quiz

Line and continuum emission/absorption

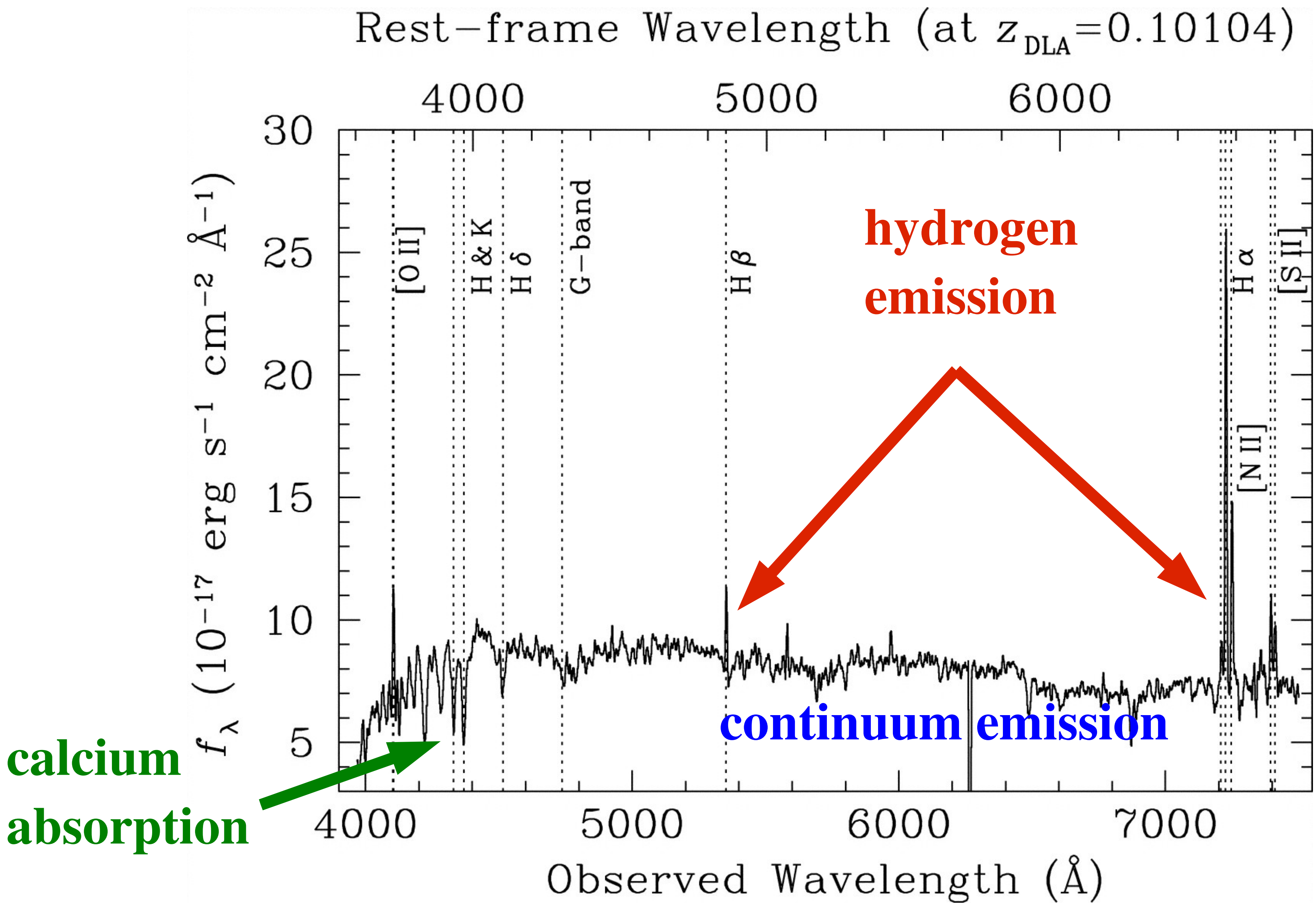
When we look at astronomical spectra (at all wavelengths), we classify features in two ways:

(1) line vs. continuum (roughly, narrow vs. broad)

(2) emission vs. absorption

Note: for an absorption line to be produced, there must be "background" continuum emission to be absorbed!

Example: optical spectrum of a galaxy



Radio continuum emission

Three principal mechanisms:

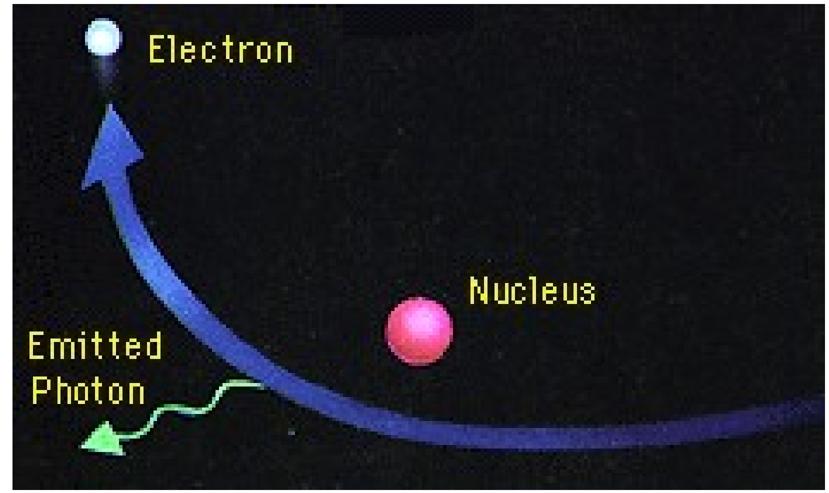
(1) free-free emission (a.k.a. "bremsstrahlung" = "braking radiation") from ionized gas

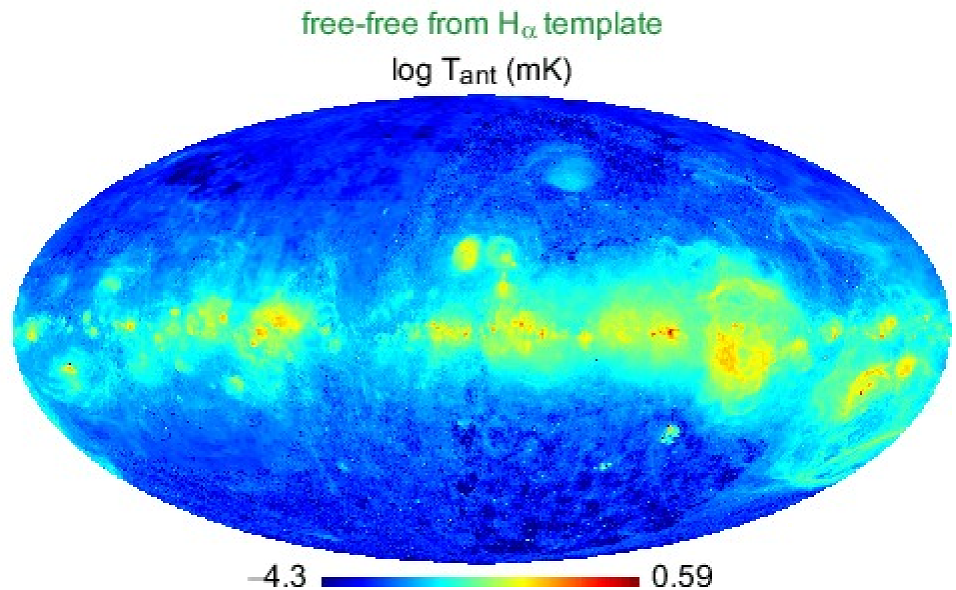
(2) synchrotron emission from electrons being accelerated in a strong magnetic field

(3) thermal emission (i.e., produced due to heat) by dust grains

Free-free emission

Mechanism: electrons are accelerated by the Coulomb potential of ions (higher temperature ⇔ faster motions ⇔ higher-energy photons).

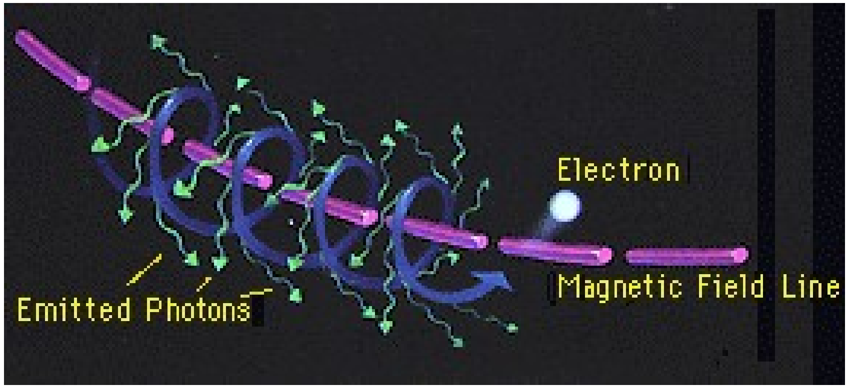


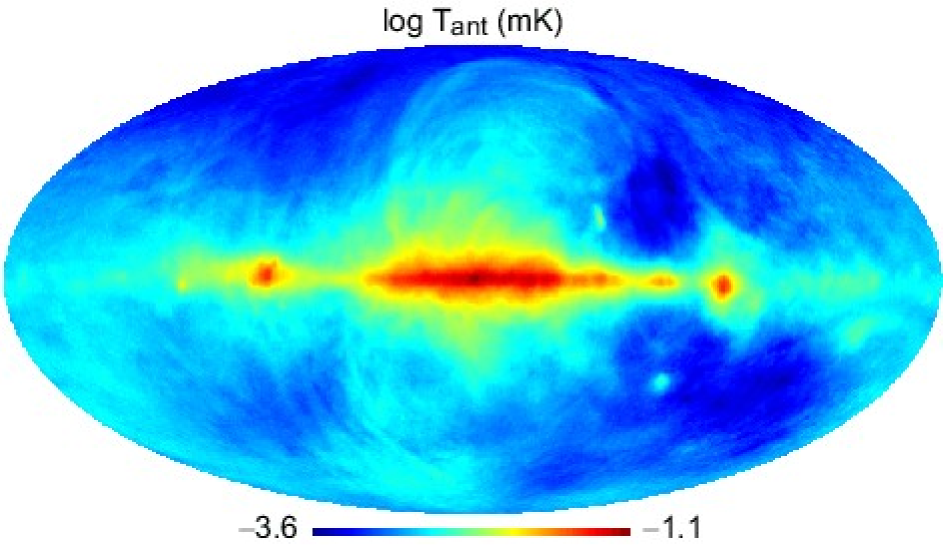


Burigana et al. (2004):
free-free emission from Milky Way at 100 GHz

Synchrotron emission

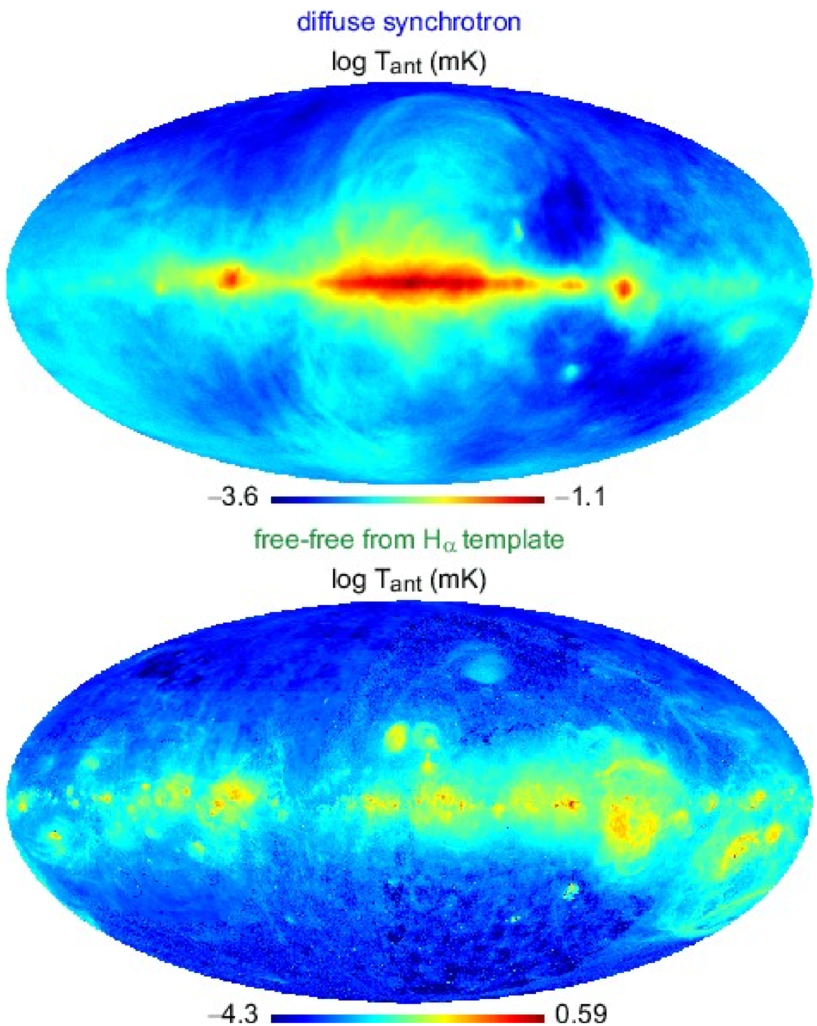
Mechanism: electrons are accelerated along helical trajectories in magnetic fields (stronger magnetic fields ⇔ higher-energy photons).





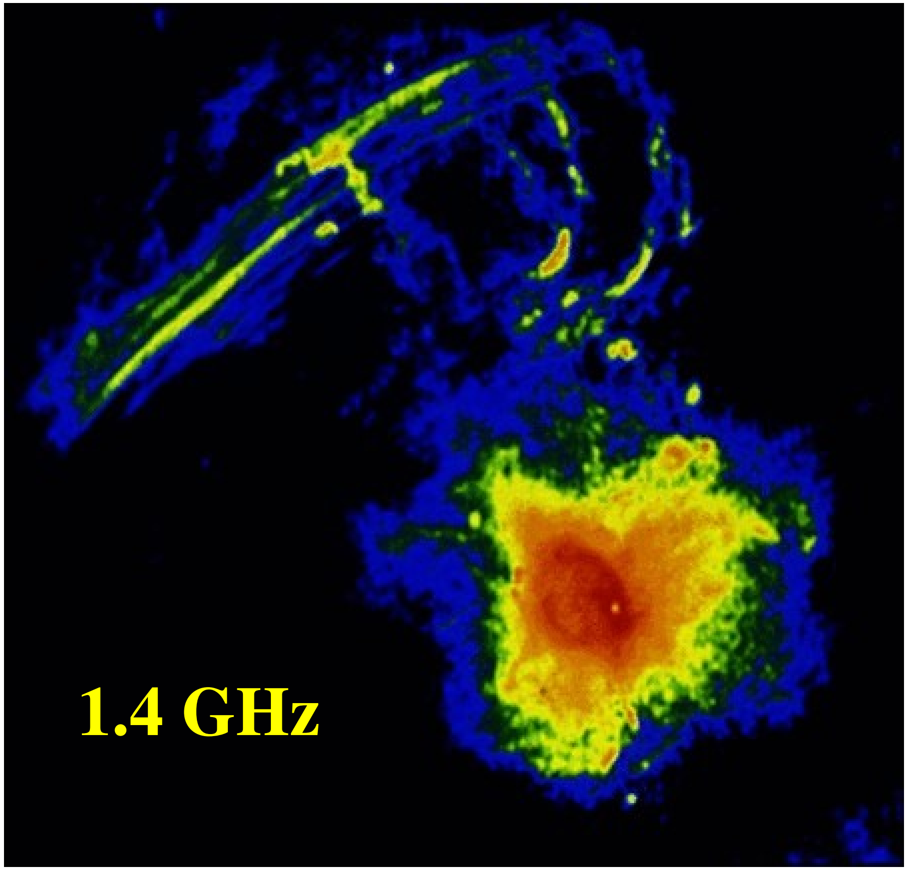
Burigana et al. (2004): synchrotron emission from Milky Way at 100 GHz

Free-free vs. synchrotron emission



Why do these look different?

Galactic Center filaments: which mechanism is responsible?

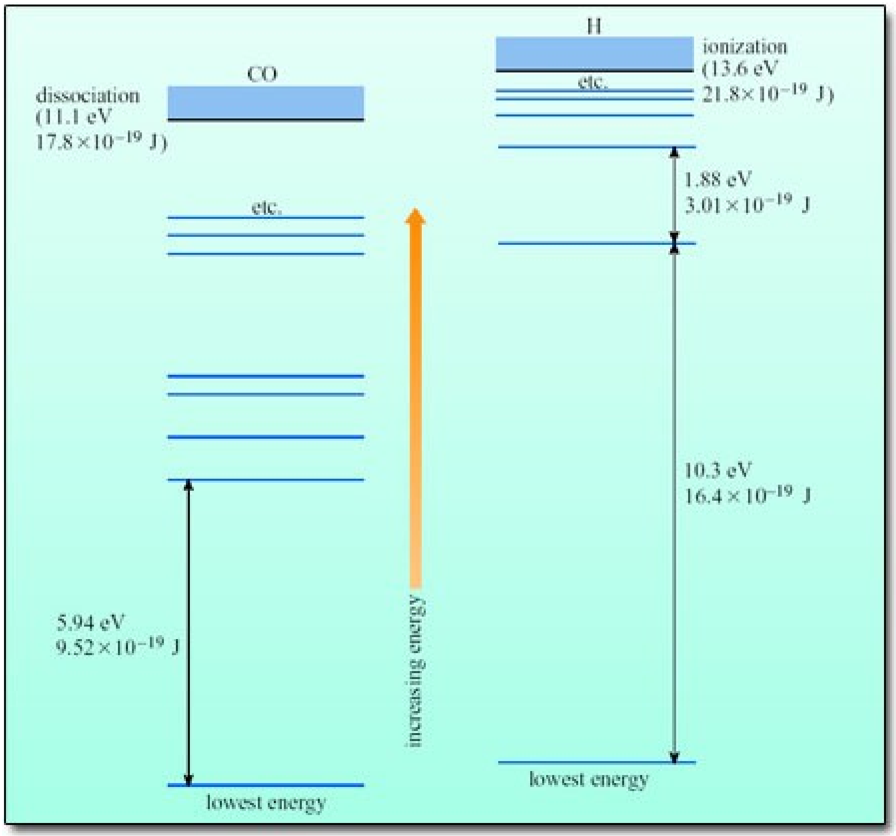


Line emission

A sharp line feature occurs when there is a transition in the electronic or spin state of an atom, or in the electronic, vibrational, or rotational state of a molecule.

This sharp feature is broadened by line-of-sight motions in the emitting/absorbing material (i.e., by the Doppler effect).

Electronic transitions

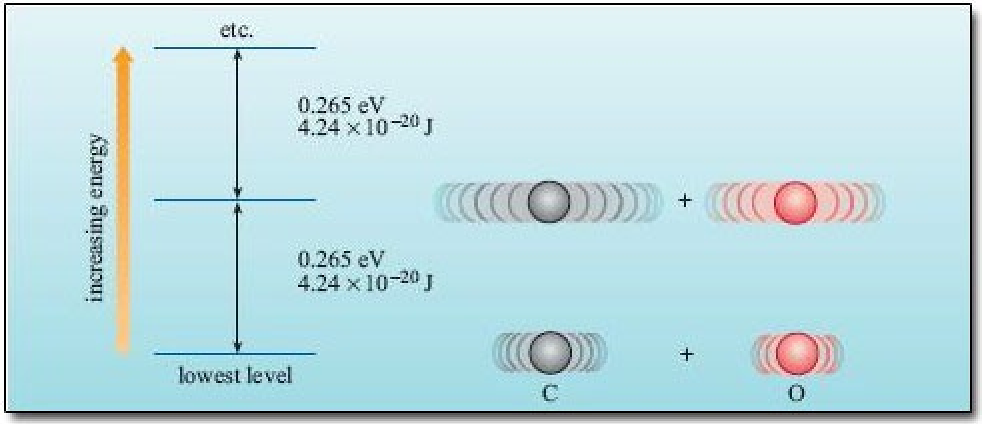


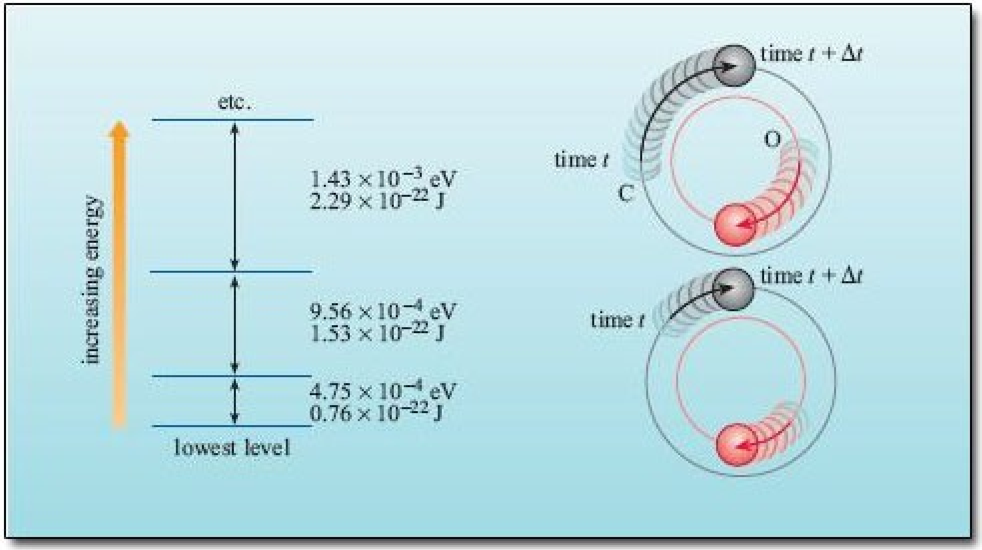
When an electron in an atom or molecule drops from a higher energy level to a lower energy level, a photon is emitted.

An incoming photon of the right wavelength/frequency can also be absorbed.

Courtesy of Open University.

Vibrational and rotational transitions





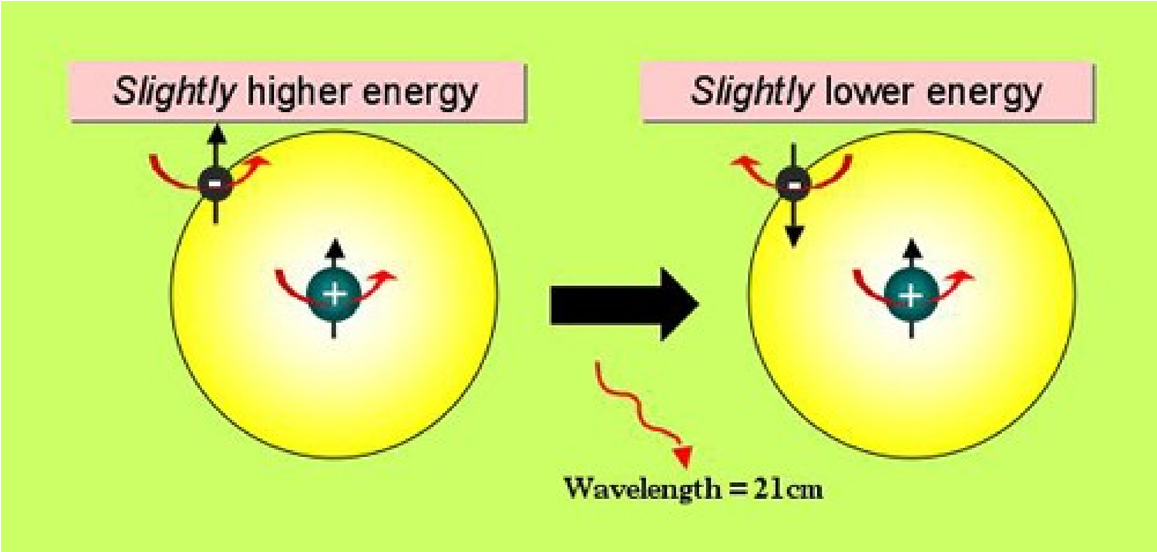
Courtesy of Open University.

Molecules also have quantized levels of vibrational and rotational energy (spacings are higher for the former).

Transitions are associated with absorption/emission of photons.

The key "spin flip" transition: 21cm H line

In a H atom, when the electron and the proton switch from having parallel spins to having antiparallel spins, a 21cm photon is emitted.



Doesn't trace ionized or molecular gas – just neutral atomic gas!

Courtesy of Swinburne University.